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Some Historical Relationships between Science and Technology with Implications for Behavior Analysis

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The relationship between science and technology is examined in terms of some implications for behavior analysis. Problems result when this relationship is seen as one in which science generally begets technology in a one-way, or hierarchical, relationship. These problems are not found when the relationship between science and technology is seen as two-way, or symmetrical, within a larger context of relationships. Some historical examples are presented. Collectively, these and other examples in the references weaken the case for a prevailing one-way, hierarchical relationship and strengthen the case for a two-way, symmetrical relationship. In addition to being more accurate historically, the symmetrical relationship is also more consistent with the principles of behavior analysis.

Key words: science, technology, behavior analysis, graphing

Recent studies of the contexts for scientific discoveries and technological innovations have found an extensive network of influences from earlier and related crafts and technologies as well as earlier and related sciences and philosophies. Collectively, these studies show that sometimes the knowledge of science is a source for the practices of technology, and sometimes the practices of technology are a source for the knowledge of science. To highlight the two-way nature of this relationship, a symmetrical view of the relationship between science and technology has been contrasted with an older, hierarchical view (Barnes & Edge, 1982; Layton, 1971, 1976). The symmetrical view holds that, collectively, science and technology interact in a reciprocal two-way relationship. The hierarchical view holds that science produces technology in a prevailing one-way relationship. An examination of the evidence for and the implications of these views provides a clarifying context for some issues in behavior analysis.

For instance, a trend of increasing distinctions has been noted between the experimental analysis of behavior and applied behavior analysis with some dispute as to whether this is good or bad news (Baer, 1981; Deitz, 1978; Hayes, Rincover, & Solnick, 1980; Michael, 1980; Pierce & Epling, 1980; Poling, Picker, Grosset, Hall-Johnson, & Holbrook, 1981). Some of the arguments for different interpretations appear to be based on different meanings for *applied* (Dietz, 1983). In particular, two different senses of *applied* reflect the distinction between hierarchical and symmetrical relationships between science and technology.

For example, *applied* may be used to mean that principles derived from the experimental analysis of behavior are followed to produce technological effects. This usage implies a one-way, hierarchical relationship between basic research and later applications of that research. However, *applied* may also be used in a broader sense to describe the behavior analysis which occurs in outcome-oriented fields of behavioral technology. It is sometimes assumed that the same hierarchical relationship should exist here as well and that deviations from this relationship are improper or abnormal. The following, however, will show that this broader usage entails a symmetrical two-way relationship between scientific knowledge and technological practice. Many of the questioned differences between outcome-oriented field settings and theory-oriented laboratory settings can then be seen as proper or normal (cf. Azrin, 1977). The following will also point

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out how the symmetrical view is more consistent with some basic principles of behavior analysis.

THE HIERARCHICAL VIEW

According to the hierarchical view, science produces new knowledge whose practical implications are then worked out by technology (Barnes & Edge, 1982, p. 148). This view has been advanced on occasion by both scientists and engineers. One of the earliest sources for this view is Joseph Henry, one of the founding fathers of science as a profession in America. In 1832, Henry stated:

> Every mechanic art is based upon some principle of one of general laws of nature.... The more intimately acquainted we are with these laws the more capable we must be to advance and improve [*the useful*] arts.... Almost every art particularly it be of extensive utility is founded on the accumulated discoveries of scientific men for centuries. (1832/1972, pp. 383–388)

In 1853, Henry restated his position somewhat more strongly: "In order that an important invention may be successful, two conditions must be favorable: First: It must be possible; that is, the scientific principle on which it is to be founded must be known. Second: The invention must be wanted" (1855/1886 p. 315). Every important invention now depends upon the knowledge of science.

In more recent times, Vanevar Bush, an engineering professor from M.I.T. and director of the Office of Scientific Research and Development during World War II, is quoted by Layton (1976) as the most important spokesman for this view: "Basic research . . . creates the fund from which the practical applications of knowledge must be drawn. New products and new processes . . . are founded on new principles and new conceptions . . . painstakingly developed by research in the purest realms of science" (p. 689). Later comments by Bush suggest this statement was part of public relations efforts that included retitling engineers as scientists since "the engineer was a kind of second-class citizen compared to the scientist" (Bush, 1970, p. 54).

As these quotations indicate, the hierarchical view supports assumptions of mechanistic causation. There is a simple, direct causal relationship between scientific knowledge and technological practice. Technological innovations are caused by scientific discoveries. If there is an important practical innovation, then there must have been scientific knowledge that caused it. The time lag between a scientific discovery and its application measures, perhaps, the time it takes for a practical need to develop or the competence of technologists.

Support for the priority of scientific theoretical knowledge can be traced to a time when social barriers separated the dominant literary minority in philosophy and religion from the practical activities of artisans, traders, navigators, and slaves. Among the privileged literate minority of ancient Greece, for example, knowledge was more analytical than practical. For Aristotle, science was the understanding of things in terms of causes supplied by reasoning. A similar meaning is found in the etymology of the word. *Science,* which entered English in the 14th century, is derived from the Latin *scire,* to know, which is akin to *scindere,* to cut. In contrast, the root word for technology, which entered English in the 17th century, is *techne,* art or craft, which is akin to the Greek *tekton,* builder or carpenter, and the Latin *texere,* to construct or weave. The constructive knowledge of how to do things was attained through practice and experience, which Aristotle called *techne.* This practical knowledge was set apart from scientific knowledge as different in kind and basically irrelevant to it (Drake, 1980, p. 40).

More recent support for the claim that science is the basis of technology seems to derive from the 19th century (cf. Bohme, Van Den Daele, & Krohn, 1978; Layton, 1976). At that time specializations within science and engineering became institutionalized in professional groups, and the terms *scientist* and *technologist* were first used in their modern sense (Buchanan, 1976). Science and technology could then be seen as enterprises of separate subcultures with some resemblance to the ancient class distinctions between those who produced written publications and those who produced practical works. A major difference from the earlier class distinctions, however, is that science and technology were now both closely related unions of theory and practice. Science has its theoretical and its practical sides, and technology has its theoretical and its practical sides.

Within science, support for the primary importance of abstract knowledge can be seen in publications that stress the logical, analytical side of the scientific enterprise. As a result, accounts of how a scientific discovery was actually made have often been misleading (e.g., Drake, 1980; Westfall, 1973). Even today, scientific publications often attach more importance to logical demonstrations of what can be concluded from the data than to comprehensive descriptions of the contingencies that produced the report (cf. Hodgkin, 1976; Rymer, 1988; Skinner, 1972; Watson, 1968).

Within behavior analysis, the hierarchical view can be seen in Epling and Pierce's (1986) account of the "abstract research model":

> An alternative perspective stipulates that basic research must be conducted to discover and investigate principles of behavior. In this view, research may be completely abstract with no concern for external validity. It is assumed that the prediction and control of socially-significant behavior will follow from the discovery of basic laws. This implies that application and technology are informed by basic research but that there is little reciprocal influence. Such a position only permits applied behavior analysts to act as "consumers" of basic principles. The result of the asymmetrical interaction may be that applied researchers are assigned the role of technicians and analytical inquiry is not reinforced.
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> A perspective that gives paramount importance to internal validity and holds that principles of behavior only emanate from the laboratory may be termed the "abstract research model." Many basic researchers appear to adopt this model. Interestingly, the model has been accepted by applied analysts who frequently see themselves as "the implementers of principles." (p. 91)

If applied analysts are fundamentally implementers of laboratory principles, their technology in applied fields is primarily dependent on what is done in the laboratory. This exemplifies the hierarchical view.

Consistent with this view, the assumption that science produces technology may be fairly explicit. For example, in contradicting William James's contention that definite programs and methods of instruction cannot be directly deduced from psychology, Skinner (1968) claimed that "the so-called experimental analysis of behavior has produced if not an art at least a technology of teaching from which one can indeed 'deduce programs and schemes and methods of instruction'" (p. 59). In this statement, the technology of teaching depends on the experimental analysis of behavior. In turn, programs and methods of instruction follow from this technology as products of a deductive enterprise.

Interestingly enough, detailed case studies that show a prevailing hierarchical relationship between science and technology are difficult to find. Presumably, contextual details are not thought to add much to the if-then relation between the scientific discovery and the technological innovation, and a simple reference to a scientific discovery and its technological application is considered sufficient. On a closer look, however, some examples turn out to be quite different from the simple relationship that was cited.

As an illustration, Skinner (1987, p. 114) has interpreted an example by Mosteller (1981) as an instance of the time lag between a scientific discovery and its practical use. This example purported to show that lemon juice was scientifically discovered as a cure for scurvy in 1601, but more than 190 years passed before the British navy began to use citrus juice on a regular basis and another 70 before scurvy was wiped out in the mercantile marine.

The actual events from which this example was drawn, however, do not illustrate the time lag between a scientific discovery and its practical use as much as they illustrate the time lag between erratically effective practices and a scientific discovery of the significant causal relationship. Some, but not all, of the early practical recommendations for preventing or curing scurvy were effective.

Scientists now know that scurvy, which was the deadliest of all sea diseases, is easily prevented and cured by vitamin C, which is in many vegetables and highly concentrated in citrus fruits. The determination of this relationship, however, was slow to evolve.

As early as the 13th century, Gilburtus Anglicus advised sea travelers to take along lemons and other fruits and vegetables (Keevil, 1957, p. 18). More specifically, on his sea voyage of 1593, Richard Hawkins stated that sour oranges, lemons, and Aqua Doctoris Stephani, an acid tasting mixture of distilled water and 21 ingredients, were the best cures he had seen for scurvy. In 1601, James Lancaster attributed the freedom from scurvy of the men on his flagship, as compared to the numerous cases that occurred in the three other ships of his fleet, to

> The Juice of Limons, three spoonfuls every morning fasting: not suffering them to eat any thing after it till noone. This juice worketh much the better, if the partie keepe a short Dyet, and wholly refraine salt meate, which salt meate, and long being at the Sea is the only cause of the breeding of this Disease. (Purchas, 1905, p. 396)

There is no evidence in Mosteller's citation, however, that Lancaster's observations were the result of a planned experiment as Mosteller implies. Rather, they were a report of actions accompanied by successful results with interpretations that included relevant as well as irrelevant features.

Although these examples reflect successful practices, they failed to establish a clear causal relationship between scurvy and a dietary deficiency that could be remedied by vegetables as well as citrus fruit. Various interpretations for causal relationships continued to be offered, some of which were apparently influenced by the success with citrus fruit but were still wide of the mark. For example, some attributed causal efficacy to a sour taste and used oil of vitriol as a cure. Others used lemon juice as a mouth wash without swallowing it (Keevil, 1957, p. 223).

James Lind's field experiment on board H.M.S. Salisbury 1746–1747 was the first controlled dietetic experiment on record (Lloyd, 1961, p. 123). Publishing his findings in 1753, Lind found that oranges and lemons were the most effectual remedies and also stipulated the necessity of a vegetable diet as a preventative. Lind, however, had not gotten everything quite right. He mistakenly recommended preserving lemon juice by boiling it for several hours before bottling (Vitamin C is readily oxidized and easily destroyed in cooking). Even then, Lind's evidence had to make its way against other conflicting reports before it was clear that lemons would prevent and cure scurvy. By 1796 the mistake in heating the juice for preservation had been recognized, and Thomas Trotter could declare that "scurvy can always be prevented by fresh vegetables and cured effectually by the lemons or preserved juice of the fruit. . . . Whatever may be the theory of the sea scurvy, we contend that recent vegetable matter imparts a *something* to the body which fortifies it against the disease" (Lloyd, 1961, p. 131). It was not until the laboratory studies of Albert Szent-Gyorgi and Charles King in 1928–1933 that this "something," which we now call Vitamin C, or ascorbic acid, was isolated.

Long before the laboratory discovery of Vitamin C, the British Admiralty in 1795 ordered a daily issue of ¾ oz of lemon and 2 oz sugar in a seaman's grog. Less expensive West Indian limes soon replaced lemons, and British sailors acquired the name of *limeys.* Lime juice became obligatory for seamen on merchant ships in 1844, and the Merchant Shipping Act of 1867 appointed an Inspector of Lime Juice at bonded warehouses (Lloyd, 1961, p. 32).

When we consider that scurvy was the first disease to be recognized as caused by a dietary deficiency, it may be less surprising that the cause and cure of scurvy took a while to be discovered. Since it took a while for scurvy to develop, there were often more conspicuous events preceding the outbreak of scurvy, such as foul air and eating salted meat, which commanded attention and interpretation. The story of the cure for scurvy is not the story of the slow lag between an early scientific discovery and its practical application. Rather, it is the story of how long it can take before somewhat haphazardly successful practical actions can be scientifically explained.

Implications

One implication of the hierarchical view is that technology cannot progress without the knowledge of science. This implication has long been used in support of funding for basic research with the suggestion that the money spent on basic research will be returned manyfold in technological productivity. Another, related implication is that a technology is more productive, the more closely it is governed by scientific knowledge. There is often a strongly prescriptive recommendation, then, that technology should follow scientific principles. Following the hierarchical view, it is understandable that some behavior analysts see a troublesome inconsistency whenever applied behavior analysis does not depend on the principles of the basic science of behavior.

From the hierarchical perspective, the proper role for a technology of behavior seems clear: follow the principles of the science of behavior. However, this guiding principle soon runs into problems. To begin with, there is substantial disagreement about many of the principles of behavior within the experimental analysis of behavior itself (Perrone, Galizio, & Baron, 1988). Further, even when there is agreement, there is no guarantee that principles derived from the contingencies of some contexts will function well in other contexts. In addition, if we take "follow the principles of the science of behavior" to be the guiding principle for a technology of behavior, then this principle itself is in conflict with behavioral principles that favor an empirical approach and responding to data.

For example, in addressing the practical side of his scientific activity, Skinner (1972) has stated:

> I never attacked a problem by constructing a Hypothesis. I never deduced Theorems or submitted them to Experimental Check. So far as I can see, I had no preconceived Model of behavior—certainly not a physiological or mentalistic one and, I believe, not a conceptual one.... Of course, I was working on a basic Assumption—that there was order in behavior if I could only discover it—but such an assumption is not to be confused with the hypotheses of deductive theory. It is also true that I exercised a certain Selection of Facts but not because of relevance to theory but because one fact was more orderly than another. If I engaged in Experimental Design at all, it was simply to complete or extend some evidence of order already observed. (p. 112)

Skinner goes on to comment on experiments by Keller and Sidman: "It is no longer necessary to describe avoidance and escape by appeal to 'principles,' for we may *watch* the behavior develop when we have arranged the proper contingencies of reinforcement, as we later watch it change as these contingencies are changed" (p. 117). Skinner's position does not mean that theories are unimportant but that "theories are based upon facts; they are statements about organizations of facts" (Skinner, 1972, p. 302). Although it may be doubted that any fact is completely free of theory, the thrust of Skinner's views is clear. It is more fundamental for theory to evolve from empirical events than to have events deduced from formal theory.

If this is good advice for the scientist, it is difficult to see why it should not also be good advice for the technologist. In particular, it is difficult to see why this advice should be reversed for the technologist. It seems an odd behavioral inconsistency that the technologist should be more under the control of theory than the scientist and less under the control of practical events than the scientist.

THE SYMMETRICAL VIEW

In the symmetrical view of science and technology, science influences technology and technology influences science, with no general hierarchical domination of one over the other (cf. Barnes & Edge, 1982; Bohme et al., 1978; Jevons, 1976; Keller, 1984; Langrish, Gibbons, Evans, & Jevons, 1972; Layton, 1971; Ziman, 1984). Sciences are also influenced by their own traditions of sciences and philosophies, and technologies are influenced by their own traditions of crafts and technologies.

This multiply interactive view has emerged in recent years largely from descriptive case studies of technological innovations. For example, Jevons (1976) cites a finding of about 900 inputs of information for 30 British new product innovations; 300 of these inputs were attributed to external sources, the others coming from the individuals and firms concerned. About 100 of the external units of information had scientific sources and 200 had technological sources.

Collectively, such studies present a dense network of contextual interactions for technological innovations. Scientific discoveries and technological innovations both emerge within complex contexts with influences from many sources. Sometimes an influence on technology from science may be pointed to. Sometimes an influence on science from technology may be pointed to.

There are many opportunities for influences between science and technology because they share many of the same values, but not in the same order. Science is distinguished from technology by the priority that science gives to knowledge and technology to practice (cf. Azrin, 1977; Bunge, 1966; de Solla Price, 1982; Hall, 1978; Keller, 1984; Layton, 1971; Polanyi, 1962; Vincenti, 1988). Publications are prominent in science's search for abstract theories, laws, and principles that are generally true across different contexts. The scientist uses technological products and practices as a means in investigations that support, modify, or reject conceptual formulations. Verbal analysis is an end product. Toward this end, the scientist values detachment in predicting final states from initial states, prefers to be guided by exactly precise values, studies simple variables, and uses instruments of measurement like the clock, thermometer, or voltmeter that respond to only one variable so that there is an unequivocal relationship of data to variables in advancing universal comparability and generalization. Technological innovations evolve as a by-product of the search for knowledge, and instruments that may have been devised to explore or demonstrate a theory often have a greater impact on technology than the theory itself (Keller, 1984, p. 174).

By contrast, in seeking practical effects in particular situations, the technologist is concerned with knowing how, with doing and making, and with gains in efficiency and effectiveness that have practical importance. For the technologist, verbal analysis and formulations are largely means. Theories and principles are among the many sources that technology draws on in selecting and combining various components to find a design for successful action. An effective combination of variables is primary, their isolation is secondary. In this endeavor, the technologist is an active participant in conditional forecasts and cybernetic control, is satisfied with safe and wide intervals centered on typical values, and will usually attempt a number of practical measures at the same time. Principles emerge from practice, and formal theory evolves from practical success as a sort of by-product (Bohme et al., 1978, p. 243).

Although technology in the broad sense (including arts and crafts) may influence science without using much in the way of instrumentation—for example, in dietary or human management practices—the more conspicuous historical influences occur with technological instruments. Such influences are found in theories based on these instruments and their use; for example, physical optics (the microscope and telescope), pneumatics (the pump and barometer), thermodynamics (the steam engine), and information theory (the telegraph and telephone) (Bohme et al., 1978, p. 233; Pierce, 1961). Self-regulating devices, like the governor on the Boulton-Watt steam engine, as well as simpler machines, have influenced psychological concepts of behavior (cf. Boakes, 1984, p. 182; Danzinger, 1983), but the simpler machines have had the longer tradition. Skinner (1972), for example, has identified fountain mechanisms as a source for Descartes' views on body movement and the concept of the reflex.

In addition to its products, technology has also influenced science through its methods; for example, its disposition to omit unobservables:

> Engineering sciences did not postulate unobservables. Their example was, therefore, a challenge to physics. They contributed to the critical reexamination of the foundations of physics which took place in the latter 19th century. But the engineers themselves contributed little to this movement; it was carried forward by physicists under the banners of positivism and energeticism. (Layton, 1971, p. 579)

The scientific analysis of behavior, which has been disposed to omit unobservables, has been influenced by other engineering values as well, such as control (cf. Pauly, 1987). The adoption of these technological values may explain some of the immediate success behavior analysis had in moving from the laboratory to the field, which probably strengthened the hierarchical assumption that science begets technology.

One of the strongest influences of technological method on science has been in measurement. An historical overview of graphing, a common feature of behavior analysis, indicates how extensive the web of influences may be for a particular area of development. Many of these relationships are not seen if we selectively look only at Descartes' analytical geometry and the graphic records that followed or if we look only at Lindsley's (1974) account of how the practice of collecting daily frequency records of student performance in the classroom was based on Skinner's laboratory research. When we step back a bit for a larger view, we find that Lindsley's recommendations for graphing were also influenced by a practical need to make it easier for students to read each other's graphs. And if we step back further still, we find many influences, from both science and technology, for the various contributions to graphing in general and to classroom graphing in particular.

Early graphical representations of measurement met practical needs in map making and land surveying. Among various practical uses of geometric measurement, Egyptian surveyors, or rope-stretchers, appear to have frequently remeasured land reflooded by the Nile in order to determine the taxes for the proportion of crop-bearing land that survived the floods. By around 1500 B.C. the Egyptians had developed a systematic guide to practical problems in geometry that included graphical representations of rectangular, trapezoidal, triangular, and circular areas. Around 300 B.C. Euclid's *Elements* presented a formal statement of geometric principles (cf. Beniger & Robyn, 1978; Herodotus, 1972; Kline, 1972).

In the 17th century, the invention of mechanical recorders followed a sharp increase in other new practical measurement instruments. Many of these new measuring instruments were now used in natural philosophy as part of the union of practice and theory that characterized the scientific revolution (Bennett 1986; Drake, 1980). Although recordings by mechanical devices date back to the water clock and the odometer of Ctesbius (3rd century B.C.) and Hero (2nd century A.D.) in Alexandria, the first known use of paper for graphic representation occurred around 1600 in machines for map making using a hodometer and compass. Scores of different mechanical recorders were then invented that produced moving line graphs of natural time series for temperature, barometric readings, wind speed and direction, rainfall, tidal movements, and so on. These recorders included the weather clock, with revolving drum, of Cristopher Wren, with further developments by Robert Hooke, and the Watt indicator for recording pressure and volume in the steam engine (Hoff & Geddes, 1962).

In 1764, James Watt (1736–1819), a craftsman who made mathematical instruments at the University of Glasgow, attempted to find a relationship between steam pressure and boiling point. Measurement was not easy and he obtained only five results to begin with: "From these elements I laid down a curve, in which the abscissae represented the temperatures and the ordinates the pressures, and thereby found the law by which they were governed, sufficiently near for my then purpose" (Tilling, 1975, p. 198). William Playfair (1759–1823) later became a draftsman in Watt's workshop.

Playfair had little formal schooling but had served as an apprentice with Andrew Meikle, the inventor of the threshing machine, and had been introduced to graphing by his older brother John, a well-known mathematician and geologist. After leaving Watt's workshop, Playfair made important contributions to the development of graphing and "may be called the father of the graphic method in statistics" (Funkhouser, 1937, p. 273).

Graphing, however, had yet to achieve widespread acceptance, in spite of longstanding precedents for graphing in a 10th–11th century graph of planetary orbits on a time grid, in Nicole Oresme's (1320–1382) graphical illustrations of 13 theoretical functional relationships, in Edmund Halley's 1686 fitting of a hyperbolic curve to his plotting of barometric readings against sea level, and in the numerous inventions of mechanical recorders. It was usually considered more appropriate to record data in tabular form. Graphs from recording machines were commonly converted to tables, and graphing in general was occasionally rejected as "a plaything without importance" (Funkhouser, 1937, p. 295).

Finally, in the 19th century, earlier work on graphing was reappreciated; enthusiasm for graphs spread among statisticians, engineers, and scientists such as Adolphe Quetelet (1796–1874), Charles Minard (1781–1870), and John Herschel (1792–1871); and the word *graph* entered English as a noun and verb. The following paragraphs present some of the developments in logarithmic scales, the telegraph, and kymograph which have a traceable influence on behavioral psychology and related applied fields.

Leon Lalanne, the French engineer, introduced a logarithmic grid for graphs in 1843. Stanley Jevons, the economist, developed semilogarithmic paper in 1863 and published the first instructions on the use of graph paper in 1879 (Beniger & Robyn, 1978). Later, some of the early data from Skinner's cumulative recorder was also plotted on logarithmic coordinates, which was a standard procedure at that time for the analysis of data in biological, physical, and engineering work (Coleman, 1987). Today, the semilogarithmic grid is an essential feature of the standard celeration chart in precision teaching.

In its original inception, the telegraph patented to Morse in 1840 was, as its name implies, a method of graphically recording messages sent from a distance. Morse used a rotating drum in one adaptation that produced a spiral record on paper which could be removed from the drum and bound in a book as a record. The telegraph key and graphic records were later put to frequent use in psychology. For example, Dresslar (1892) used a cumulative recorder in his study of the rate at which a person can tap on a Morse key; Bryan and Harter (1897, 1899) examined the cumulative records of the rate at which Morse code is sent and received by expert and novice telegraphers; and Fred Keller (1977) designed instruction for improving the reception rate of Morse code. Keller was a professional telegrapher before he became a behavioral psychologist, and his approach to the problem of telegraph code reception shows the interplay of his background in technology and in science:

> The problem for me resolved itself into one of *stimulus discrimination,* and the white rat in the Skinner Box was my experimental model. I decided that this little animal, pressing a lever whenever a tone was sounded in his chamber, was really a radio operator, working with a one-signal code and a very simple "copying" response, the bar-press. Except, perhaps, for one important difference: if the rat performs this function, he typically gets a pellet of food for his trouble, whereas the operator's reward is not so easily observed. (1977, p. 28)

Keller's extensive work in this area led to a practical achievement in the U.S. Army's adoption of his instruction as one of two official code training devices.

Karl Ludwig introduced his invention of the kymograph for recording blood pressure in 1847, acknowledging that "this apparatus is based on a principle that the famous Watt is supposed to have first introduced" (Hoff & Geddes, 1959, p. 18). Ludwig's introduction of graphic registration in physiology is credited with "creating and establishing whole schools of physiological endeavor" (Hoff &

Geddes, 1959, p. 5). Skinner (1979, p. 56), who did his dissertation in physiology, later designed his cumulative recorder by modifying a kymograph.

The first graphs of learning curves were published by Edward Thorndike from his dissertation on animal intelligence in 1898. Thorndike (1913) later used numerous graphic representations of practice curves, many of which were obtained on the telegraph and typewriter, to examine the amount, rate, changes in rate, permanence, and limit of improvement in human performance as well as the conditions under which improvement occurred. Apparently influenced by the telephone exchange in which lines are connected and disconnected, Thorndike interpreted behavior in terms of S-R connections and restated the "Spencer-Bain" principle as the law of effect in 1911 (Boakes, 1984). The references to "satisfaction" and "discomfort" in this law were restated more objectively by the philosopher Bertrand Russell (1927/1970, pp. 35–36), and the process covered by this law was later incorporated in the three-term formulation of Skinner's operant behavior.

Meanwhile a considerable technology of human management had been developing in industry. Early efforts to provide feedback to workers made little use of exact measurement. For example, the color at the front of Robert Owen's "silent monitor," a four-sided piece of wood hung on a hook by each employee, told the conduct of the worker during the preceding day: (1) white for exellent, (2) yellow for good, (3) blue for indifferent, and (4) black for bad. The daily numbers for each worker were later recorded in a book (Carmony & Elliott, 1980). With the advent of standardized parts in the 19th century, however, the acceptance or rejection of a particular worker's production (and the payment received) could be based on the precise measurements of an inspector (Hindle & Lubar, 1986, pp. 231–233). Later, Frederick Taylor (1911, p. 127), the engineer who is regarded as the founder of scientific management, recommended that workers keep their own records. Henry Gantt (1919/1974), another prominent engineer in the scientific management movement, was a strong advocate of progress charts. Gantt's records received nationwide attention when he selected "rivets driven" to indicate progress in shipbuilding during World War I and daily records of rivets driven by shipyard crews were published in the newspapers (Alford, 1934, p. 199).

As part of his application of the principles of scientific management to education, Franklin Bobbitt (1913) recommended graphical displays for recording individual student progress:

> This putting of the educational product in the forefront of education means the establishment of a continuous record of progress in the case of each of the products. . . . Such a continuous record must be kept, naturally, in the case of each of the many score educational products so as to show how each pupil at any time measures up against the standard. Simpler than parallel columns of figures would be graphical representation, the only objection being the necessity of increased space and labor. (p. 23)

Bobbitt believed "it ought to be possible for the pupil himself to test his speed ability whenever he likes to see if he has attained the standard that has been set for him" (1913, p. 45). Later, Carlton Washbourne (1922) advocated students measuring their own performances and keeping "definite records of their improvement from day to day" (p. 203). A few years later, John A. O'Brien (1926) recommended self-charting in reading: "The direction or slant of the line tells the whole story. . . . The pupil becomes determined to 'make that line go up' . . . the individual graph made one of the strongest appeals to the pupils and proved one of the most effective instruments in stimulating their speed in reading" (pp. 74–75). By 1936, Dvorak, Merrick, Dealey, and Ford, who acknowledged both behavioral and scientific management sources for their work on typewriting instruction, were advocating many if not most of the charting principles that were later used in precision teaching (Joyce & Moxley, 1988). Since then, additional features of graphic recording in educational settings have been addressed in celeration measurement (McGreevy, 1984), opportunity-bound behavior (Baer, 1986), performance feedback systems (Van Houten, 1984), and checklists for young children (Studwell & Moxley, 1984).

In the above account, graphing has been influential in both science and technology and has been influenced by both science and technology. Current practices for graphing in education have sources in earlier educational practices, in the technology of scientific management, and in behavioral science. In turn, graphing in behavioral science has sources in previous psychology, in the related science of physiology, and in technology. If we wished to assert a one-way influence of technology on science, we could selectively group many of the above examples to show this. Such a grouping, however, would be as arbitrarily selective as grouping a list of scientific discoveries followed by technological applications.

A collective examination of other case studies in the various references cited above shows a similar variety of influences. Some studies, like the 1968 Project TRACES by the National Science Foundation (Keller, 1984) may show a preponderant influence of science on technology. Other studies, like Vincenti's (1988) "How Did It Become 'Obvious' That an Airplane Should Be Inherently Stable?" may show a complex network of influences on a technological development with little influence from science. And some studies, such as those which have traced the development of thermodynamics from the steam engine, may show scientific theory emerging from techological innovation (Ziman, 1984). Collectively, these studies show a diverse network of influences on science and technology, including some from science on technology and some from technology on science.

Implications

The symmetrical view does not predict where any particular influence on a technological innovation must come from. The influence may come from a closely related science, a more distantly related science, a closely related technology, a more distantly related technology, or perhaps from some other source in the specific situation at hand. Accordingly, a symmetrical view does not find it necessarily inappropriate when behavior analysis in applied fields engages in practices that are not derived from the experimental analysis of behavior.

In its attention to a comprehensive examination of relationships, the symmetrical view of science and technology is consistent with the pragmatic tradition of behavior analysis (Day, 1980) that implies a contextual orientation (Hayes, Hayes, & Reese, 1988; Pepper, 1970). The symmetrical view has its strongest validity in the larger context. It is not predictive of what a local instance of a relationship between science and technology is, nor prescriptive of what it should be.

The symmetrical view is also more fully consistent with traditional behavioral positions on the relationship between theory and practice. Behavior analysis has supported the importance of developing theory from contact with the empirical events comprising the contingencies of behavior. It has also supported the importance of having theory influence what those contacts will be. The symmetrical view supports both directions of these relationships. The hierarchical view only supports the influence of theory on practice.

CONCLUSION

A hierarchical view of the relationship between science and technology receives little support from an extended examination of the evidence and is somewhat inconsistent with the empirical tradition of behavior analysis. This one-way relationship is seen only when isolated instances are selectively pointed to and considered in terms of if-then causality. In contrast, a symmetrical relationship between science and technology is more accurate historically and more consistent with the empirical tradition of behavior analysis. The symmetrical view does not imply that there will be symmetry in detail, such as an equal number and an equal

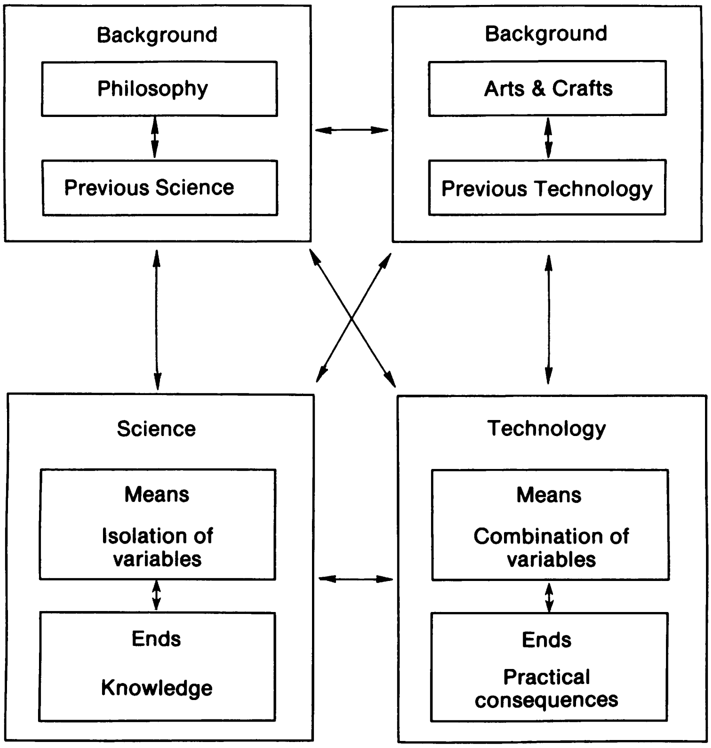

Figure 1. A simplified binary diagram of the relationship between science and technology.

strength of influences between science and technology in any particular study. Rather, the symmetrical view implies symmetry insofar as the collective existence of relationships between science and technology are two-way over a collective examination of such studies. This two-way relationship is seen as part of a larger context of relationships when a collection of case studies is examined. Figure 1 presents a simplified diagram of this contextual network without representing how any particular relationship evolves.

In both views, principles from the science of behavior are relevant to the technology of behavior, but in different ways. In the hierarchical view, the principles have a necessary, a priori relevance. In the symmetrical view, the principles have a pragmatic relevance that is conditional on practical consequences. In addition, the symmetrical view supports a contextual sensitivity in producing practical results that may lead to new principles for the technology of behavior and for its science.

These distinctions also suggest a possible reason why some behavioral applications are not successful (Baer, Wolf, & Risley, 1987), do not endure when successful (Hopkins, 1987), and are not adopted in other contexts (Pennypacker, 1986). Practitioners under the rule-governed or principle-governed control of the hierarchical view may be limited in their sensitivity to important contextual contingencies. Inasmuch as recent critiques of applied behavior analysis have emphasized contextual considerations (e.g., Baer et al., 1987), it would seem more promising for practitioners to adopt a view that supports these considerations.

REFERENCES

Alford, L. P. (1934). *Henry Laurence Gantt.* New York: Harper & Brothers.

Azrin, N. H. (1977). A strategy for applied research: Learning based but outcome oriented. *American Psychologist, 32,* 140–148.

Baer, D. M. (1981). A flight of behavior analysis. *The Behavior Analyst, 4,* 85–91.

Baer, D. M. (1986). In application, frequency is not the only estimate of the probability of behavior units. In T. Thompson & M. D. Zeiler

(Eds.), *Analysis and integration of behavioral units* (pp. 117–136). Hillsdale, NJ: Lawrence Erlbaum.

Baer, D. M., Wolf, M. M., & Risley, T. R. (1987). Some still current dimensions of applied behavior analysis. *Journal of Applied Behavior Analysis, 20,* 313–327.

Barnes, B., & Edge, D. (Eds.) (1982). *Science in context.* Cambridge, MA: M.I.T. Press.

Beniger, J. R., & Robyn, D. L. (1978). Quantitative graphics in statistics: A brief history. *The American Statistician, 32,* 1–11.

Bennett, J. A. (1986). The mechanics' philosophy and the mechanical philosophy. *History of Science, 24,* 1–28.

Boakes, R. (1984). *From Darwinism to behaviorism.* Cambridge: Cambridge University Press.

Bobbitt, F. (1913). Some general principles of management applied to the problems of city-school systems. *The twelfth yearbook of the national society for the study of education: Part I. The supervision of city schools* (pp. 7–96). Chicago: University of Chicago Press.

Bohme, G., Van Den Daele, W., & Krohn, W. (1978). The 'scientification' of technology. In W. Krohn, E. T. Layton, & P. Weingart (Eds.), *The dynamics of science and technology* (pp. 219–250). Dordrecht, Holland: D. Reidel.

Bryan, W. L., & Harter, N. (1897). Studies in the physiology and psychology of the telegraphic language. *The Psychological Review, 4,* 27–53.

Bryan, W. L., & Harter, N. (1899). Studies in the telegraphic language: The acquisition of a hierarchy of habits. *The Psychological Review, 6,* 345–375.

Buchanan, R. A. (1976). The Promethean revolution: Science, technology and history. *History of Technology, 1,* 73–83.

Bunge, M. (1966). Technology as applied science. *Technology and Culture, 7,* 329–347.

Bush, V. (1970). *Pieces of the action.* New York: William Morrow.

Carmony, D. F., & Elliott, J. M. (1980). New Harmony, Indiana: Robert Owen's seedbed for utopia. *Indiana Magazine of History, 76,* 161–261.

Coleman, S. R. (1987). Quantitative order in B. F. Skinner's early research program. *The Behavior Analyst, 10,* 47–65.

Danziger, K. (1983). The schema of stimulated motion. *History of Science, 21,* 183–210.

Day, W. (1980). The historical antecedents of contemporary behaviorism. In R. W. Rieber & K. Salzinger (Eds.), *Psychology: Theoretical-historical perspectives* (pp. 203–262). New York: Academic Press.

Deitz, S. (1978). Science versus technology. *American Psychologist, 33,* 805–814.

Deitz, S. (1983). Two correct definitions of applied. *The Behavior Analyst, 6,* 105–106.

de Solla Price, D. J. (1982). The parallel structures of science and technology. In B. Barnes & D. Edge (Eds.), *Science in context* (pp. 164–176). Cambridge, MA: M.I.T. Press.

Drake, S. (1980). Measurement in Galileo's science. *History of Technology, 5,* 39–54.

Dresslar, F. B. (1892). Some influences which affect the rapidity of voluntary movements. *The American Journal of Psychology, 4,* 514–527.

Dvorak, A., Merrick, N. L., Dealey, W. L., & Ford, G. C. (1936). *Typewriting behavior: Psychology applied to teaching and learning typewriting.* New York: American Book.

Epling, W. F., & Pierce, W. D. (1986). The basic importance of applied behavior analysis. *The Behavior Analyst, 9,* 89–99.

Funkhouser, H. (1937). Historical development of the graphical representation of statistical data. *Osiris, 3,* 269–404.

Gantt, H. L. (1974). *Organization for work.* Easton, PA: Hive. (Original work published 1919)

Hall, A. R. (1978). On knowing, and knowing how to . . . . *History of Technology, 3,* 91–103.

Hayes, S. C., Hayes, L. J., & Reese, H. W. (1988). Finding the philosophical core: A review of Stephen Pepper's World Hypotheses. *Journal of the Experimental Analysis of Behavior, 50,* 97–111.

Hayes, S. C., Rincover, A., & Solnick, J. V. (1980). The technical drift of applied behavior analysis. *Journal of Applied Behavior Analysis, 13,* 275–286.

Henry, J. (1886). The improvement of the mechanical arts. In *Scientific writings of Joseph Henry* (Vol. 1, pp. 306–324). Washington, DC: Smithsonian Institution. (Original work published 1855)

Henry, J. (1972). In N. Reingold (Ed.), *The papers of Joseph Henry* (Vol. 1). Washington, DC: Smithsonian Institution Press. (Original work published 1832)

Herodotus (1972). *The histories* (A. de Selincourt, Trans.; A. R. Burn, Rev.). Harmondsworth, Middlesex, England: Penguin.

Hindle, B., & Lubar, S. (1986). *Engines of change.* Washington, DC: Smithsonian Institution Press.

Hodgkin, A. L. (1976). Chance and design in electrophysiology: An informal account of certain experiments on nerve carried out between 1934 and 1952. *Journal of Physiology, 263,* 1–21.

Hoff, H. E., & Geddes, L. A. (1959). Graphic registration before Ludwig: The antecedents of the kymograph. *Isis, 50,* 5–21.

Hoff, H. E., & Geddes, L. A. (1962). The beginnings of graphic recording. *Isis, 53,* 287–324.

Hopkins, B. L. (1987). Comments on the future of applied behavior analysis. *Journal of Applied Behavior Analysis, 20,* 339–346.

Jevons, F. (1976). The interaction of science and technology today, or, is science the mother of invention? *Technology and Culture, 17,* 729–742.

Joyce, B., & Moxley, R. A. (1988). August Dvorak (1894–1975): Early expressions of applied behavior analysis and precision teaching. *The Behavior Analyst, 11,* 33–40.

Keevil, J. J. (1957). *Medicine and the navy 1200–1900* (Vol. 1). Edinburgh: Livingstone.

Keller, F. S. (1977). *Summers and sabbaticals: Selected papers on psychology and education.* Champaign, IL: Research Press.

Keller, A. (1984). Has science created technology? *Minerva, 22,* 160–182.

Kline, M. (1972). *Mathematical thought from ancient to modern times.* New York: Oxford University Press.

Langrish, J., Gibbons, M., Evans, W. G., & Jevons, F. R. (1972). *Wealth from knowledge.* London: Macmillan.

Layton, E. T. (1971). Mirror-image twins: The communities of science and technology in 19th-century America. *Technology and Culture, 12,* 562–580.

Layton, E. T. (1976). American ideologies of science and engineering. *Technology and Culture, 17,* 688–701.

Lindsley, O. R. (1974). Precision teaching in perspective. In R. Ulrich, T. Stachnik, & J. Mabry (Eds.), *Control of human behavior: Behaviour modification in education* (Vol. 3, pp. 387–391). Glenview, IL: Scott, Foresman.

Lloyd, C. (1961). The introduction of lemon juice as a cure for scurvy. *Bulletin of the History of Medicine, 35,* 123–132.

McGreevy, P. (1984). Frequency and the standard celeration chart: Necessary components of precision teaching. *Journal of Precision Teaching, 5,* 28–36.

Michael, J. (1980). Flight from behavior analysis. *The Behavior Analyst, 3,* 1–21.

Mosteller, F. (1981). Innovation and evaluation. *Science, 211*(4485), 881–886.

O'Brien, J. A. (1926). *Silent reading.* New York: Macmillan.

Pauly, P. J. (1987). *Controlling life: Jacques Loeb and the engineering ideal in biology.* New York: Oxford University Press.

Pennypacker, H. S. (1986). The challenge of technology transfer. *The Behavior Analyst, 9,* 147–156.

Pepper, S. C. (1970). *World hypotheses: A study in evidence.* Berkeley, CA: University of California Press. (Original work published 1942)

Perrone, M., Galizio, M., & Baron, A. (1988). The relevance of animal-based principles in the laboratory study of human operant conditioning. In G. Davey & C. Cullen (Eds.), *Human operant conditioning and behavior modification* (pp. 59–85). New York: Wiley.

Pierce, J. R. (1961). *Symbols, signals and noise: The nature and process of communication.* New York: Harper & Row.

Pierce, W. D., & Epling, W. F. (1980). What happened to analysis in applied behavior analysis? *The Behavior Analyst, 3,* 1–9.

Polanyi, M. (1962). *Personal knowledge.* Chicago: University of Chicago Press.

Poling, A., Picker, M., Grossett, D., Hall-Johnson, E., & Holbrook, M. (1981). The schism between experimental and applied behavior analysis. *The Behavior Analyst, 4,* 93–102.

Purchas, S. (1905). *Hakluytus Posthumus* (Vol. 2). Glasgow: James MacLehose.

Russell, B. (1970). *An outline of philosophy.* London: George Allen & Unwin. (Original work published 1927)

Rymer, J. (1988). Scientific composing processes: How eminent scientists write journal articles. In D. A. Joliffe (Ed.), *Advances in writing research: Vol. 2. Writing in academic disciplines* (pp. 211–250). Norwood, NJ: Ablex.

Skinner, B. F. (1968). *The technology of teaching.* Englewood Cliffs, NJ: Prentice-Hall.

Skinner, B. F. (1972). *Cumulative record* (3rd ed.). New York: Appleton-Century-Crofts.

Skinner, B. F. (1979). *The shaping of a behaviorist.* New York: New York University Press.

Skinner, B. F. (1987). *Upon further reflection.* Englewood Cliffs, NJ: Prentice-Hall.

Studwell, P., & Moxley, R. (1984). Self-recording in kindergarten: A Study in naturalistic evaluation. *Psychology in the Schools, 21,* 450–456.

Taylor, F. (1911). *Shop management.* New York: Harper & Brothers.

Thorndike, E. L. (1913). *Educational psychology: The Pychology of Learning* (Vol. 2). New York: Columbia University, Teachers College.

Tilling, L. (1975). Early experimental graphs. *British Journal for the History of Science, 8,* 193–213.

Van Houten, R. (1984). Setting up performance feedback systems in the classroom. In W. L. Heward, T. E. Heron, D. S. Hill, & J. Trapp-Porter (Eds.), *Focus on behavior analysis in education* (pp. 114–125). Columbus, OH: Merrill.

Vincenti, W. G. (1988). How did it become "obvious" that an airplane should be inherently stable? *American Heritage of Invention & Technology, 4,* 50–56.

Washburne, C. W. (1922). Educational measurement as a key to individual instruction and promotions. *Journal of Educational Research, 5,* 195–206.

Watson, J. D. (1968). *The double helix.* New York: Atheneum.

Westfall, R. S. (1973). Newton and the fudge factor. *Science, 179* (4075), 751–758.

Ziman, J. (1984). *An introduction to science studies: The philosophical and social aspects of science and technology.* Cambridge: Cambridge University Press.